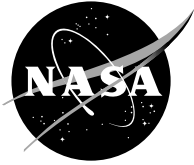


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Measured Radiation Patterns of the Boeing 91-Element ICAPA Antenna With Comparison to Calculations

Kevin M. Lambert
Analex Corporation, Brook Park, Ohio

October 2003

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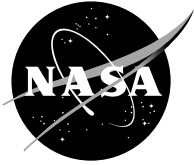
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Prepared under Contract NAS3-00145

National Aeronautics and
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Measured Radiation Patterns of the Boeing 91-Element ICAPA Antenna with Comparison to Calculations

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Abstract

This report presents measured antenna patterns of the Boeing 91-Element Integrated Circuit Active Phased Array (ICAPA) Antenna at 19.85 GHz. These patterns were taken in support of various communication experiments that were performed using the antenna as a testbed. The goal here is to establish a foundation of the performance of the antenna for the experiments. An independent variable used in the communication experiments was the scan angle of the antenna. Therefore, the results presented here are patterns as a function of scan angle, at the stated frequency.

Only a limited number of scan angles could be measured. Therefore, a computer program was written to simulate the pattern performance of the antenna at any scan angle. This program can be used to facilitate further study of the antenna. The computed patterns from this program are compared to the measured patterns as a means of validating the model.

Introduction

The Boeing ICAPA is a receive antenna which was designed with the performance goals listed in Table I [1].

Table I. ICAPA Receive Antenna Performance Goals

Performance Parameter	Goal
Center Frequency	20.7 GHz
Bandwidth	± 500 MHz
Scan Requirement	$\pm 70^\circ$ cone
Grating Lobes	None in visible space
G/T (at broadside)	-11 dB/K nominal
Polarization	RHCP
Pointing Accuracy	beamwidth

This list of goals was obtained from the ICAPA antenna manual, which also states that the goals were demonstrated during development testing.

An image of the antenna aperture is shown in Figure 1.



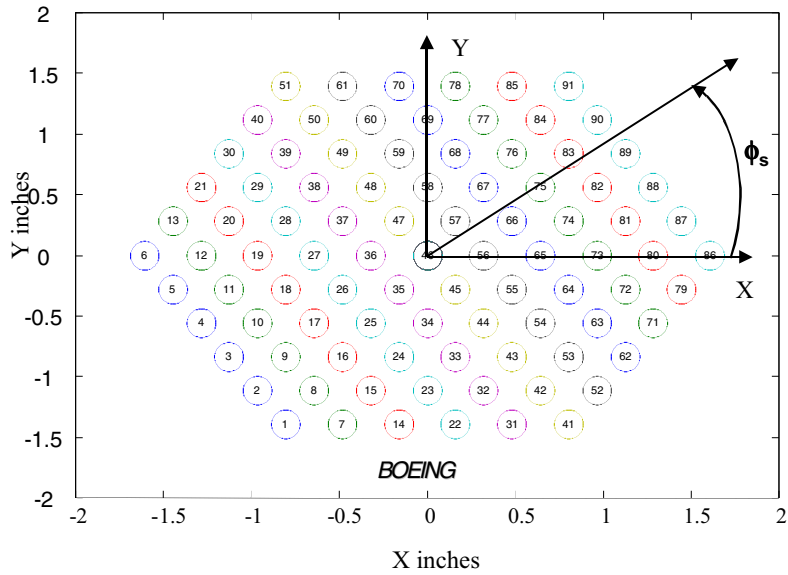
Figure 1 – The Boeing 20 GHz ICAPA Antenna.

The antenna has 91 active elements, which are cavity-backed dipoles. Each element has two MMIC chips (a low noise amplifier and a phase shifter) and an Application Specific Integrated Circuit (ASIC) logic controller. The elements are arranged with respect to the coordinate system shown in Figure 2. The spacing of the elements is $\Delta x = 0.3214$ inch and $\Delta y = 0.2784$ inch. The elements are identified by number and are grouped in columns. Column 1 consists of elements 1 through 6. Column 2 is elements 7 through 13, and so on. The X and Y axes of the antenna, defined as shown, are used to locate the elements and to specify the scan plane. The word *BOEING* assists in identifying the orientation of the antenna coordinate system during the measurements. The main beam of the antenna is defined by the scan angle pair (θ_s, ϕ_s) where θ_s is angle between the main beam direction and the Z axis and ϕ_s is the projection of the main beam direction on the X-Y plane of the antenna. Thus, ϕ_s defines the scan plane of the antenna and θ_s the amount of scan away from boresight.

Description of the Measurement

The patterns were measured in the Far-Field Antenna Range Facility at the NASA Glenn Research Center [2]. A Scientific Atlanta, Model 12A-18 standard gain horn was chosen as the transmit antenna for the tests. The horn, shown in Figure 3, was mounted at one end of the range. An earlier measurement program probed the test zone of the range at

20 GHz with this horn as the source. The measurements indicated that at this frequency, the test zone is on the order of 12 inches in diameter at a range of approximately 24 feet. Thus, this test zone is suitable for the pattern tests since the Boeing aperture is smaller than the test zone.



Columns at 120° to X axis

Figure 2 – Layout of the Boeing ICAPA Antenna Aperture.

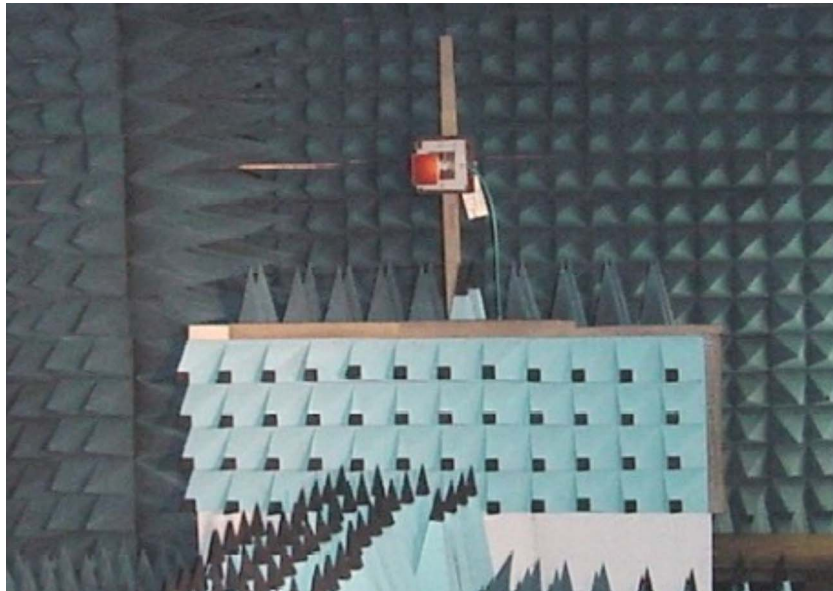


Figure 3 – Transmit Side of the Far Field Range for the Boeing ICAPA Antenna Measurements.

The Boeing antenna was mounted in the range on an azimuth over elevation positioner at the end opposite the transmit antenna. An image of the antenna in the range is shown in Figure 4. The aperture of the antenna is shown with the Wide Angle Impedance Matching Radome (WAIM), which was used during all of the measurements presented here. The antenna is shown oriented at boresight, meaning that the normal to the aperture surface (Z_{ANTENNA}) is directed at the transmit antenna along the range axis. To measure the pattern, the pedestal is rotated about its vertical axis and its response to the incident plane wave recorded. The measurement system is defined such that the rotation angle (azimuth) increases as the pedestal, and hence the antenna, is rotated to the left as viewed in Figure 4.

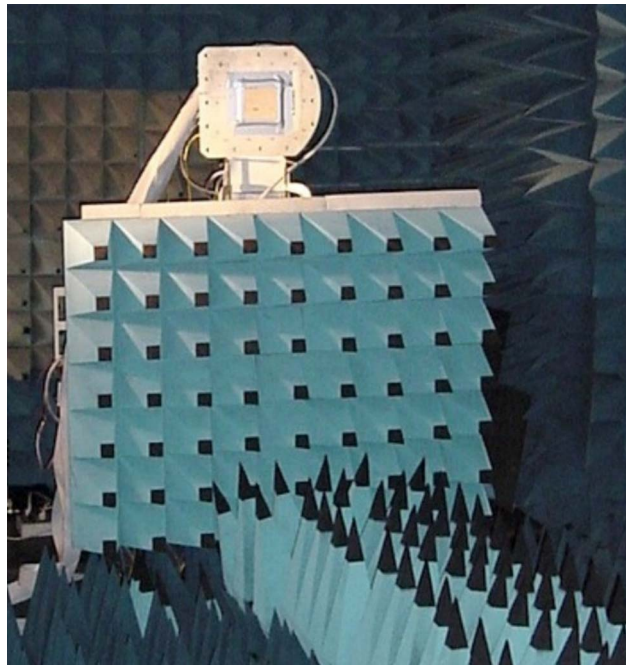


Figure 4 – The Boeing ICAPA Antenna in the Far Field Facility.

This is also seen in the bottom drawing of Figure 5, which shows a view looking down on the antenna. As the pedestal rotates clockwise, the θ_{PEDESTAL} increases and Z_{ANTENNA} moves away from the range axis, increasing θ_{PATTERN} . Assuming a standard spherical coordinate system for the antenna, $0^\circ \leq \theta_{\text{PATTERN}} \leq 180^\circ$, and thus the Horizontal axis must also define the angle, ϕ_{PATTERN} . This is important to note because, to take a pattern with the beam of the antenna scanned to (θ_s, ϕ_s) , the antenna must be rotated about Z_{ANTENNA} so that the plane of scan, ϕ_s , is in the horizontal plane. In the patterns to be presented here, the antenna was rotated about Z_{ANTENNA} to two positions. The first with X_{ANTENNA} horizontal so that $\phi_{\text{PATTERN}} = 0^\circ$ and the second with X_{ANTENNA} vertical so that $\phi_{\text{PATTERN}} = -90^\circ$.

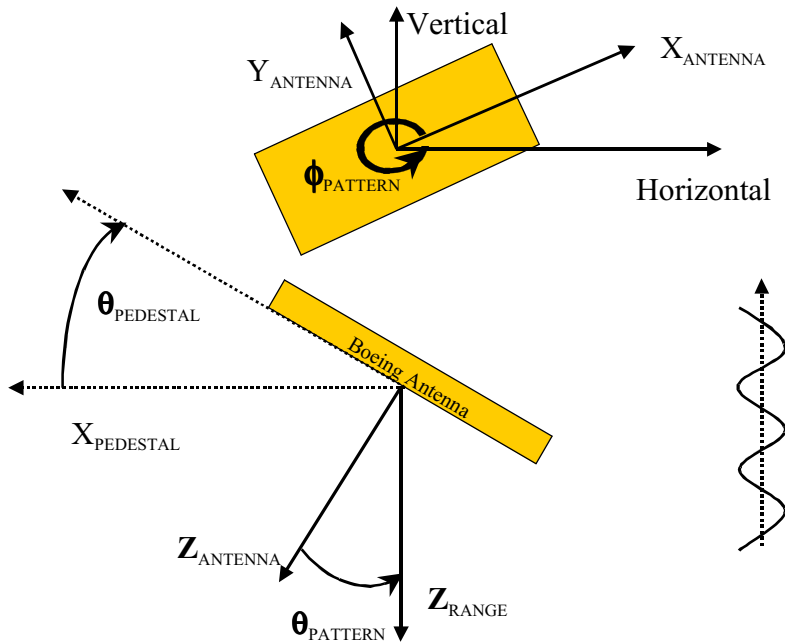


Figure 5 – Relationship of the Antenna and Pedestal Coordinate Systems.

Description of the Computer Model

A computer model of the ICAPA was developed in order to provide some information on the array without the need to perform actual measurements. The model, named *icapa_sim* was implemented in MATLAB. *icapa_sim* computes the radiation pattern using pattern multiplication of the array factor and the element factor of the array. The user provides the scan angle (θ_s, ϕ_s) and pattern plane ϕ_p desired for the calculation.

icapa_sim works by taking (θ_s, ϕ_s) and first finding the required phase shift for each individual element. In the actual array, the element phase is limited to 22.5° resolution by the 16-bit phase shifters. Therefore, *icapa_sim* uses the same algorithm as the array controller to round the necessary phase to the nearest bit, increasing the accuracy between the model and the actual antenna. With the individual element phases and the geometry of Figure 2, the array factor for the antenna is computed.

The element factor was obtained by taking an actual pattern measurement of a single element in the array. The pattern of element #46 was obtained by taking a pattern measurement of the antenna with all of the elements covered with copper tape, except for #46. The pattern was taken with no bits set on the elements phase shifter and with the antenna rotated such that $\phi_p = -90^\circ$. This measured element pattern is shown in Figure 6.

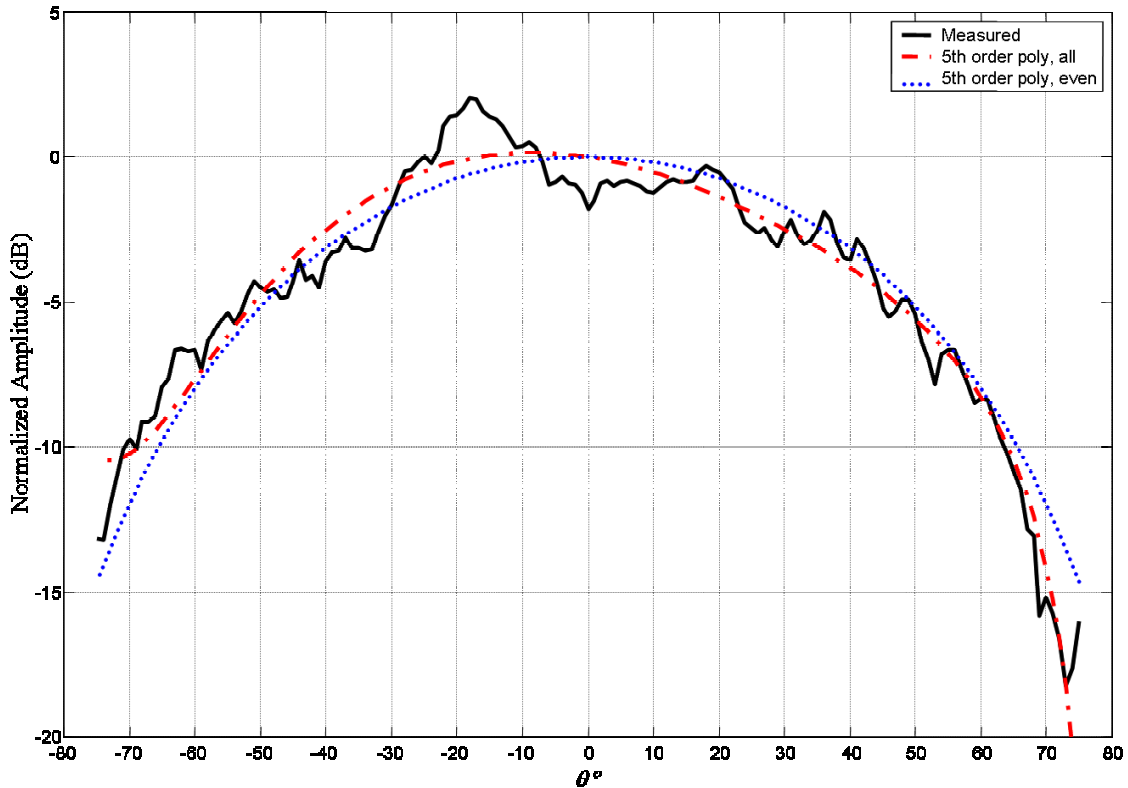


Figure 6 – Element Pattern of the Boeing ICAPA Antenna.

This pattern shows an appreciable ripple in amplitude. The likely cause of this ripple is interference from the mounting structure of the antenna. Since this mounting structure is not part of the antenna, a fifth order polynomial representation of the measured element pattern is calculated. Doing this has the effect of smoothing out the ripples of the measured pattern as can be seen in Figure 6. Note however that the fifth order polynomial is not symmetric. This is because element #46 was not located directly over the center of rotation of the pedestal during the measurement. To take this misalignment out of the model, only the even orders of the polynomial are used for the element pattern. This result is also shown in Figure 6.

Finally, the element pattern is assumed circularly symmetric. More measurements of the element alone would have to be done in order to determine if this is true. Furthermore, lack of data on the individual elements limits the model in frequency as well. Element patterns are needed as functions of frequency in order to extend it. Alternatively, a suitable analytical model of the element could be used to produce calculations at other frequencies. The accuracy of the model for the frequency used here can be determined from the patterns presented in the next section.

Comparison of Measured and Computed Patterns

Table II lists the various antenna states for which patterns were computed and measured. This group of patterns shows that the model is accurate, especially in predicting the

Table II. Summary of Boeing ICAPA Antenna Patterns

Figure	θ_{SCAN}	ϕ_{SCAN}	$\phi_{PATTERN}$
8	-60°	0°	0°
9	-40°	0°	0°
10	-20°	0°	0°
11	0°	0°	0°
12	20°	0°	0°
13	40°	0°	0°
14	60°	0°	0°
16	-60°	90°	-90°
17	-40°	90°	-90°
18	-20°	90°	-90°
19	0°	90°	-90°
20	20°	90°	-90°
21	40°	90°	-90°
22	60°	90°	-90°

For the $\phi_{SCAN} = 0^\circ$ patterns, Figure 7 shows how the antenna was oriented in the range.

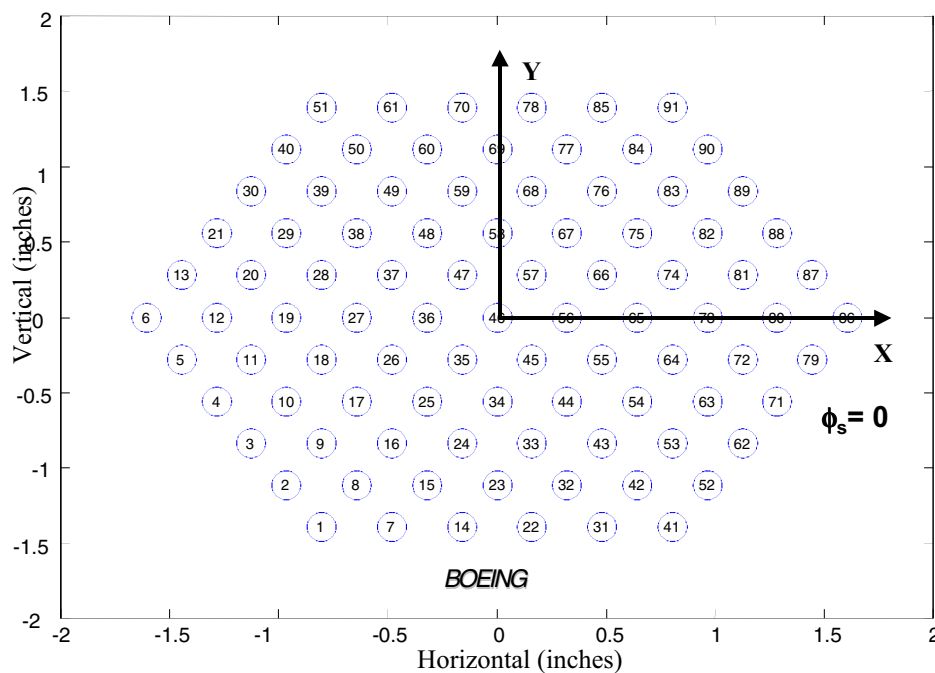


Figure 7 – Boeing ICAPA Antenna Orientation for $\phi_s = 0^\circ$ Measurements.

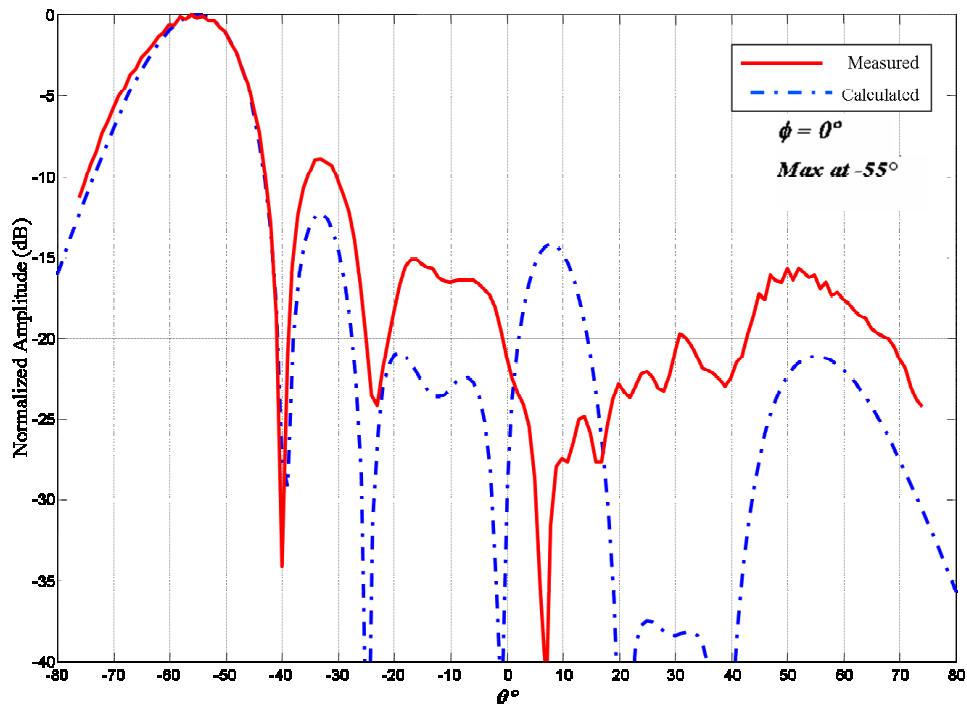


Figure 8 – Measured and Calculated Patterns for $(\theta_s, \phi_s) = (-60^\circ, 0^\circ)$.

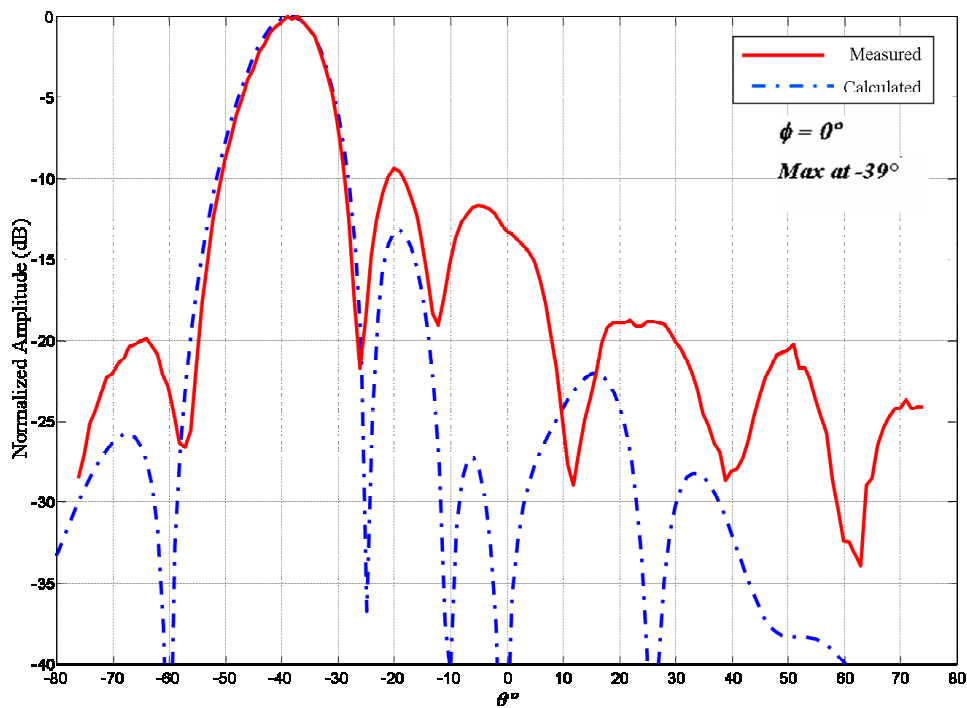


Figure 9 – Measured and Calculated Patterns for $(\theta_s, \phi_s) = (-40^\circ, 0^\circ)$.

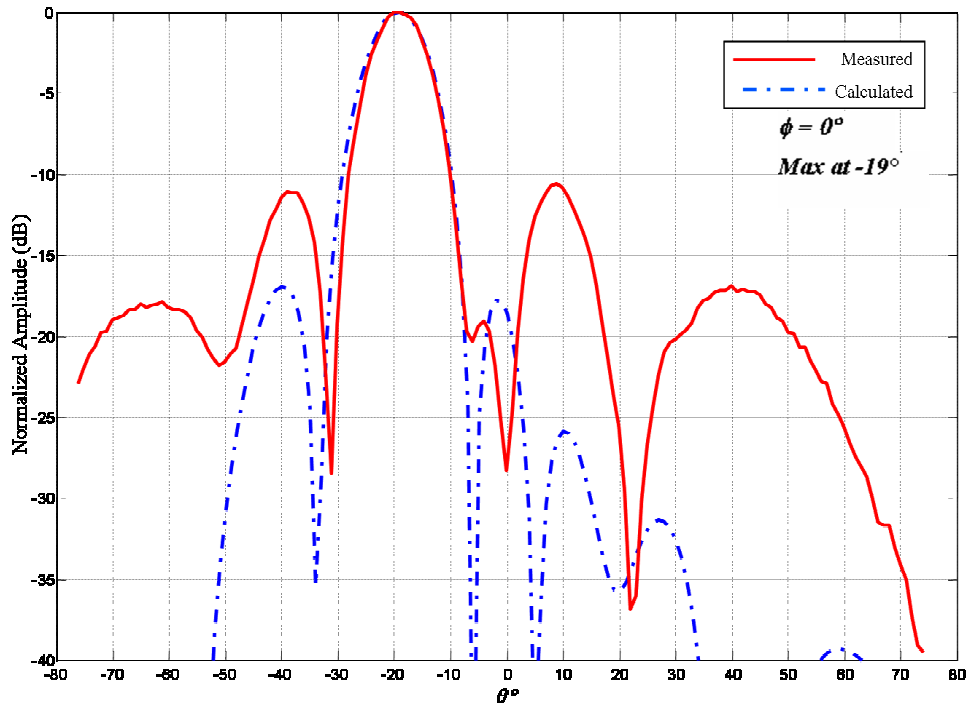


Figure 10 – Measured and Calculated Patterns for $(\theta_s, \phi_s) = (-20^\circ, 0^\circ)$.

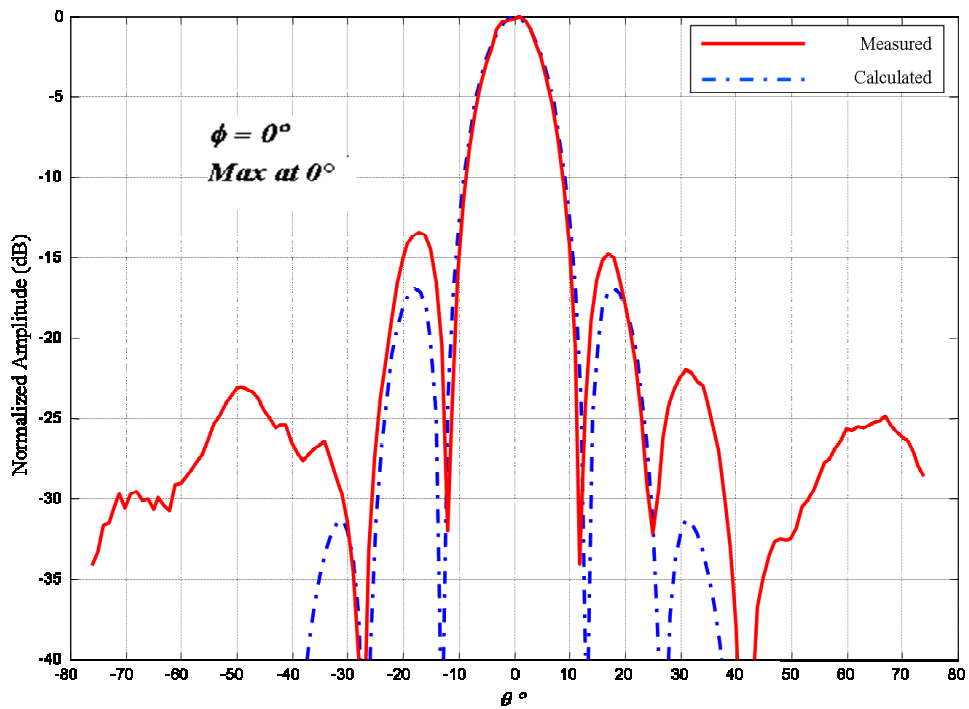


Figure 11 – Measured and Calculated Patterns for $(\theta_s, \phi_s) = (0^\circ, 0^\circ)$.

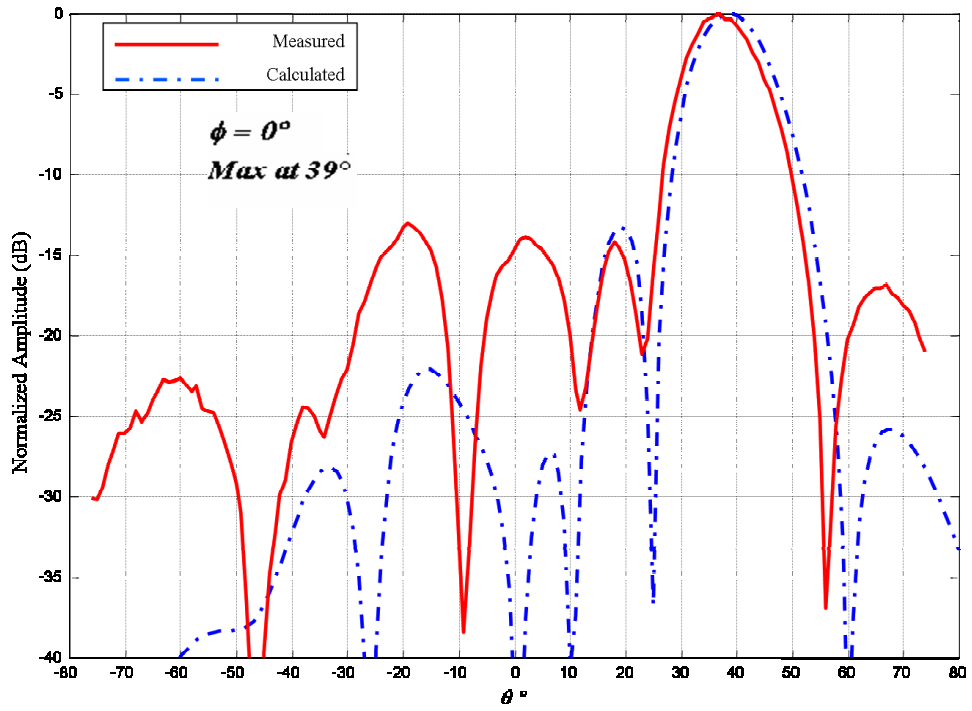


Figure 12 – Measured and Calculated Patterns for $(\theta_s, \phi_s) = (20^\circ, 0^\circ)$.

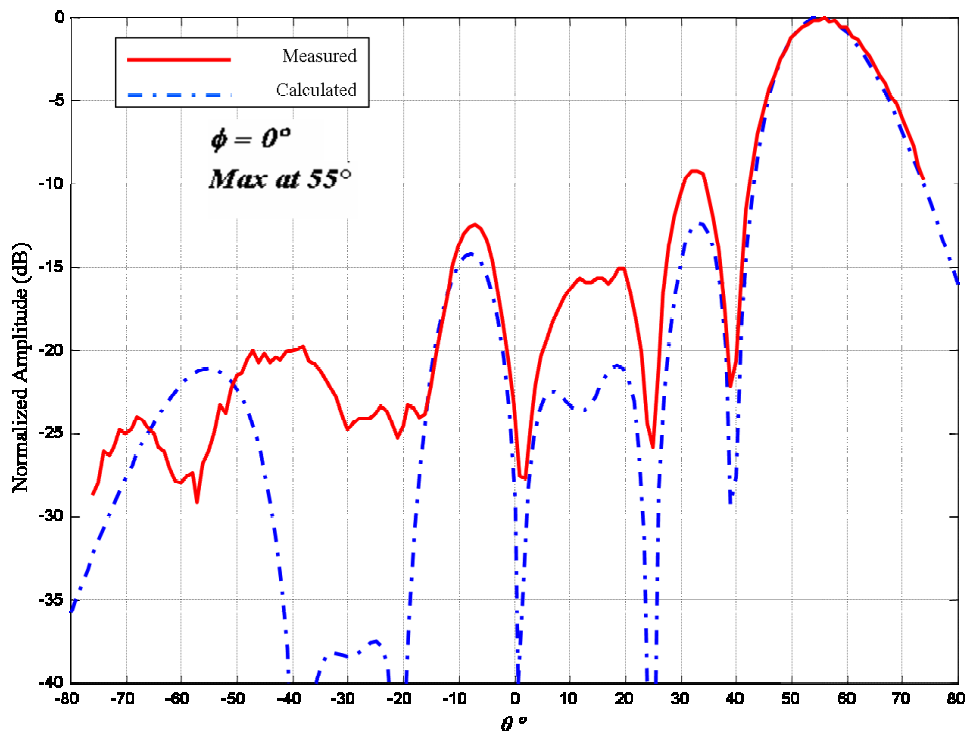


Figure 13 – Measured and Calculated Patterns for $(\theta_s, \phi_s) = (40^\circ, 0^\circ)$.

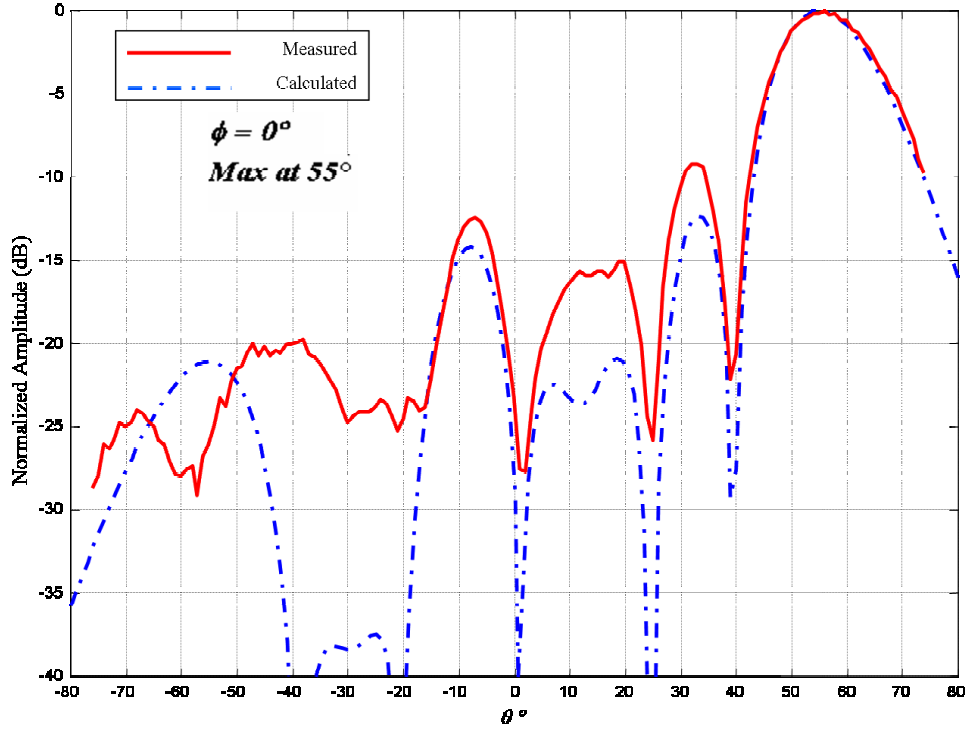


Figure 14 – Measured and Calculated Patterns for $(\theta_s, \phi_s) = (60^\circ, 0^\circ)$.

For the $\phi_{SCAN} = 90^\circ$ patterns, Figure 15 shows how the antenna was oriented in the range.

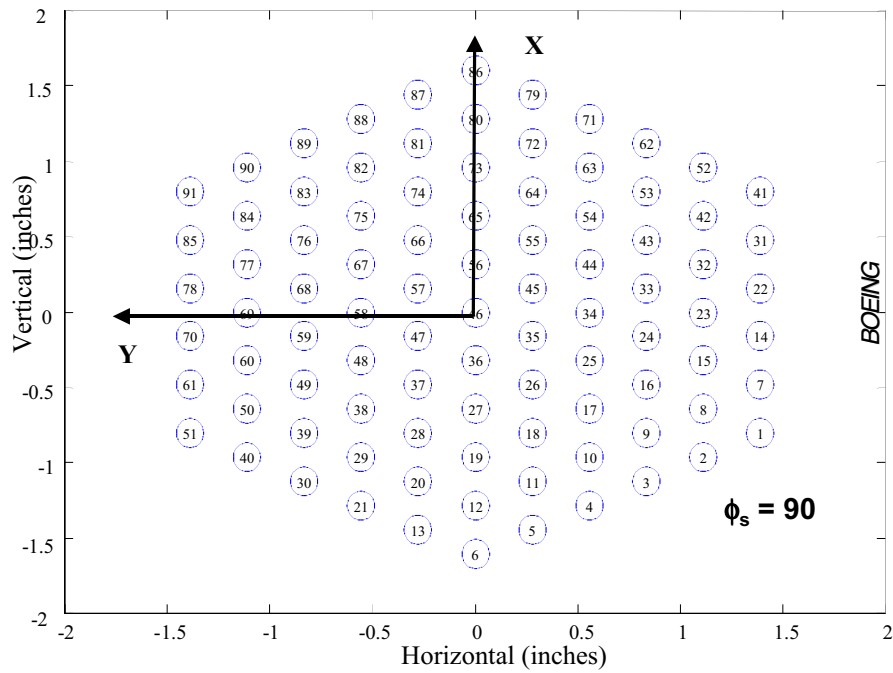


Figure 15 – Boeing ICAPA Antenna Orientation for $\phi_s = 90^\circ$ Measurements.

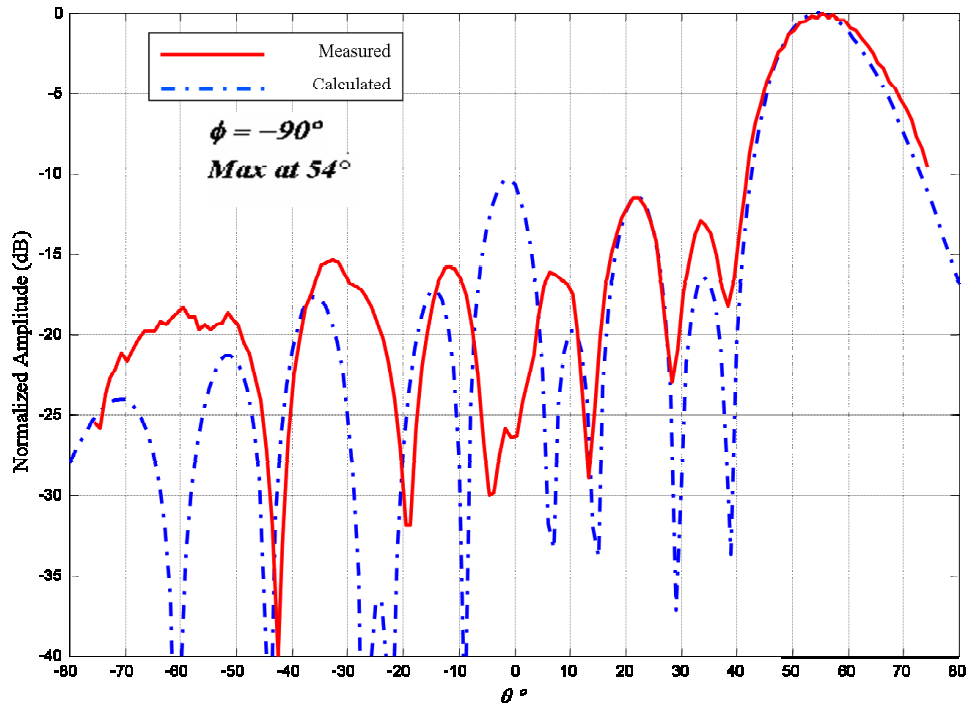


Figure 16 – Measured and Calculated Patterns for $(\theta_s, \phi_s) = (-60^\circ, 90^\circ)$.

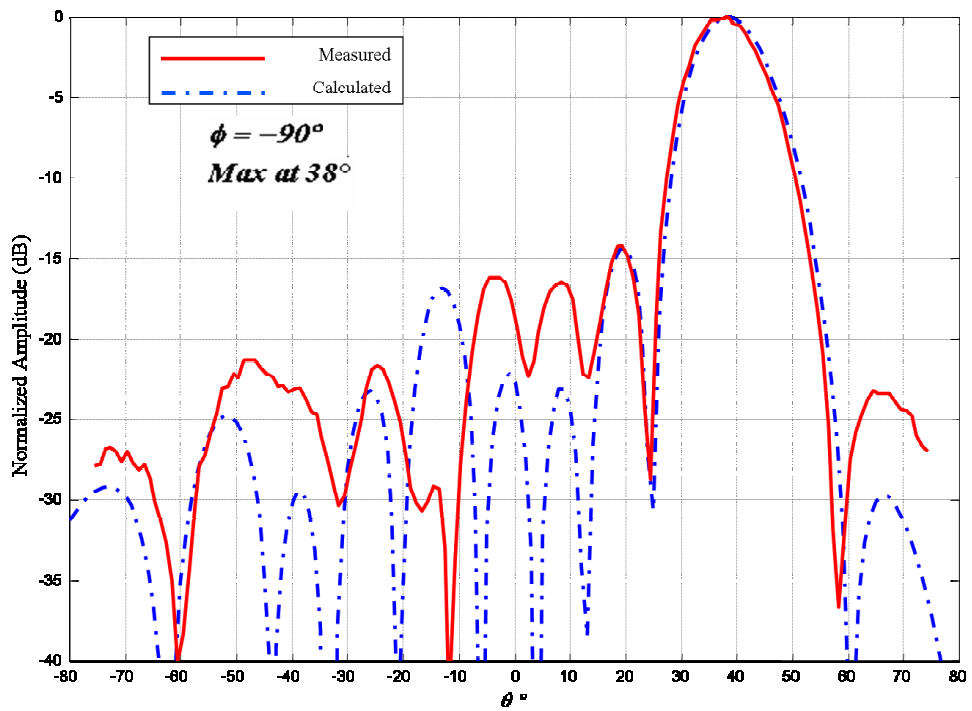


Figure 17 – Measured and Calculated Patterns for $(\theta_s, \phi_s) = (-40^\circ, 90^\circ)$.

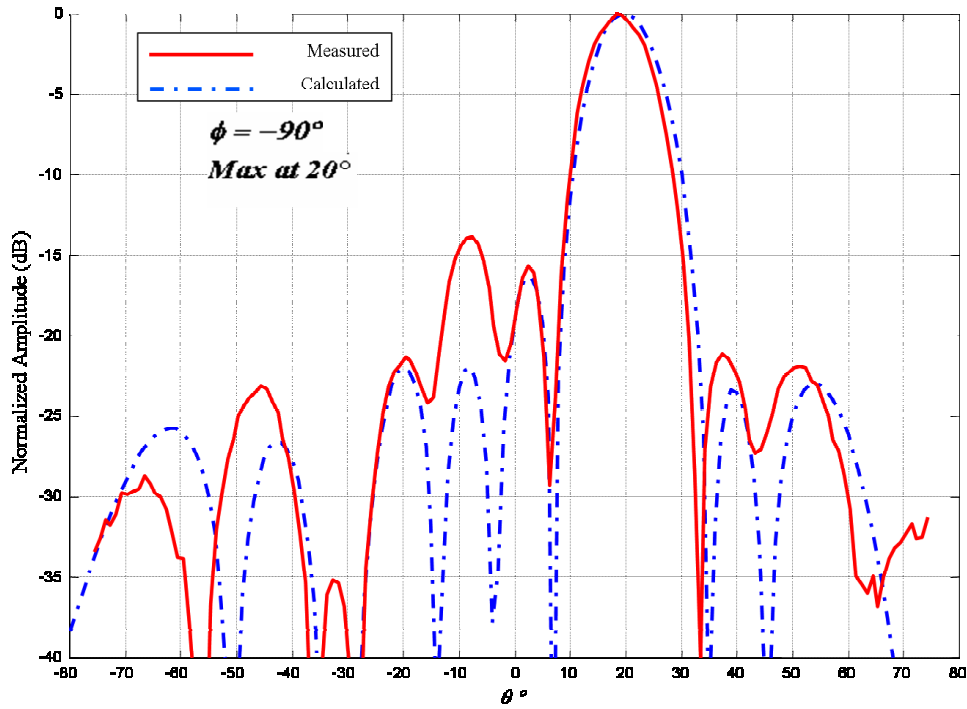


Figure 18 – Measured and Calculated Patterns for $(\theta_s, \phi_s) = (-20^\circ, 90^\circ)$.

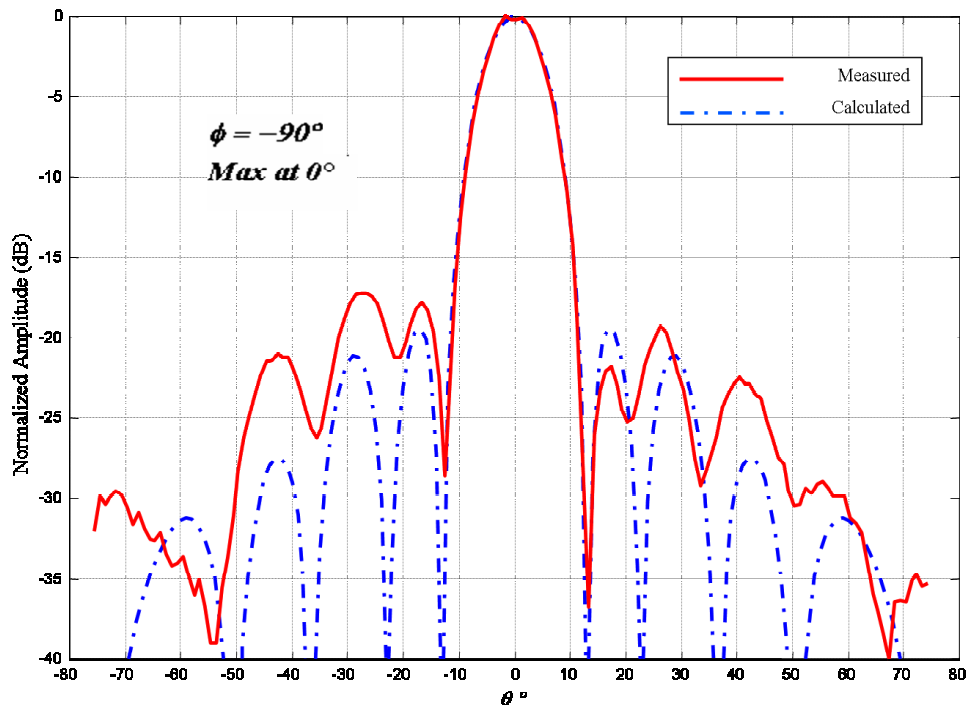


Figure 19 – Measured and Calculated Patterns for $(\theta_s, \phi_s) = (0^\circ, 90^\circ)$.

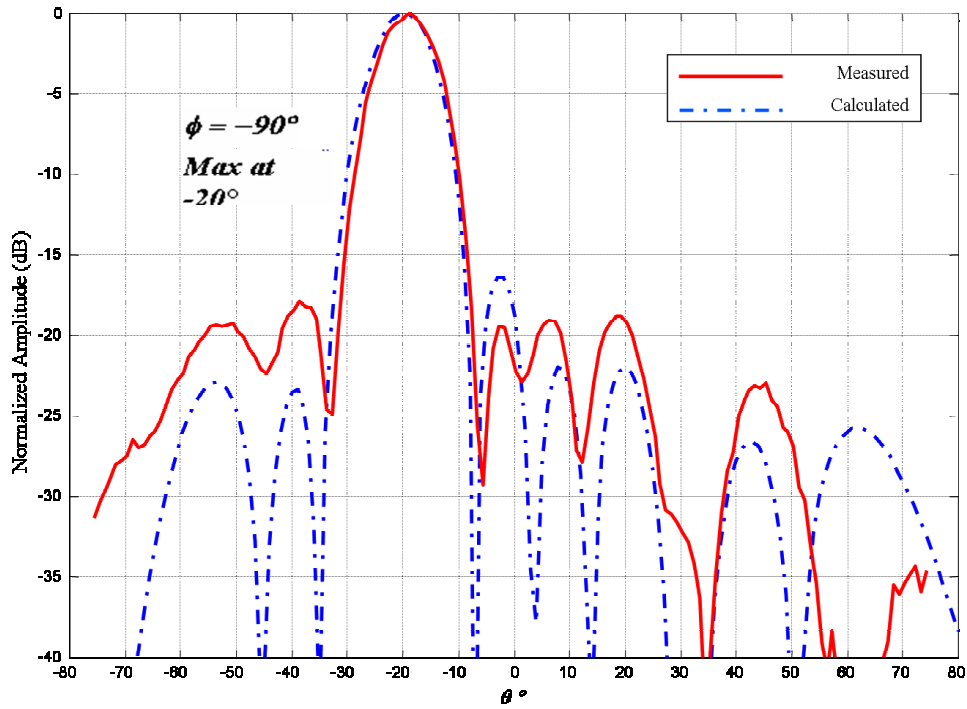


Figure 20 – Measured and Calculated Patterns for $(\theta_s, \phi_s) = (20^\circ, 90^\circ)$.

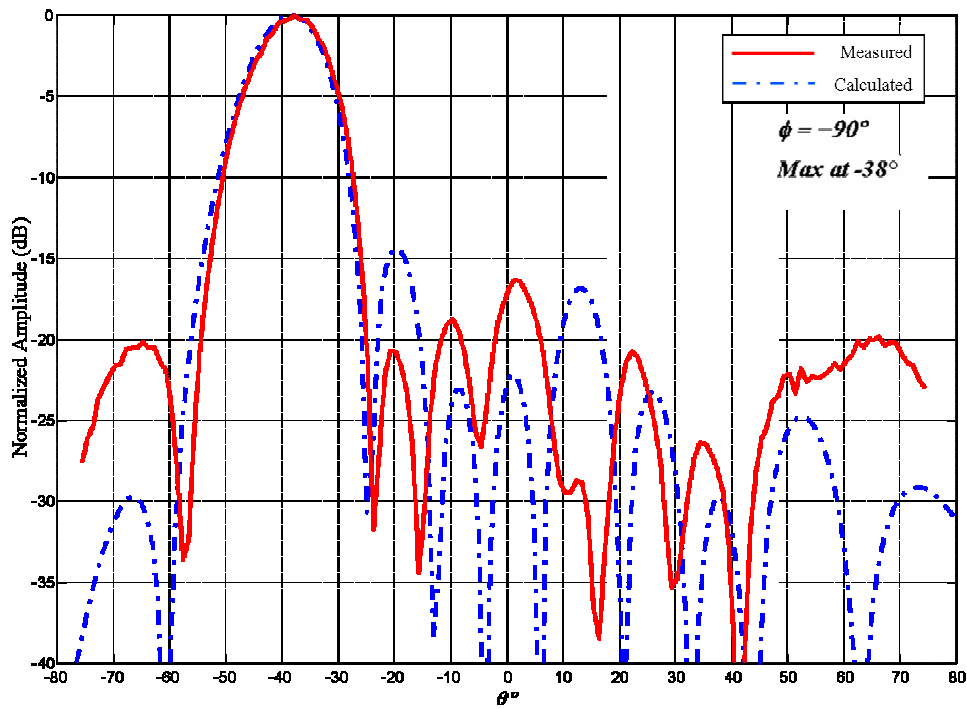


Figure 21 – Measured and Calculated Patterns for $(\theta_s, \phi_s) = (40^\circ, 90^\circ)$.

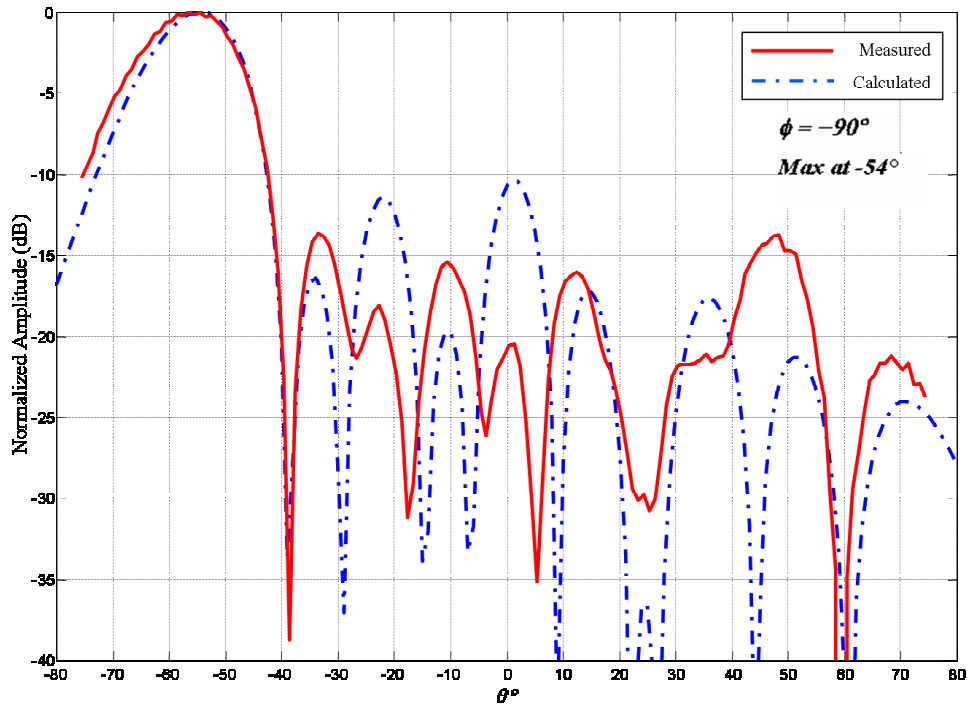


Figure 22 – Measured and Calculated Patterns for $(\theta_s, \phi_s) = (60^\circ, 90^\circ)$.

location of the scanned mainbeam and of the sidelobes. The differences in the sidelobe levels are probably due to non-ideal plane wave illumination of the Boeing antenna at all azimuth angles. Interference scattering from the edges of the Boeing antenna becomes more significant as the edge becomes more fully illuminated at off boresight angles. Since this interference happens close to the elements, each element is affected differently. Therefore, each element pattern would be different from the single element pattern used in the simulation. This effect can also be seen in the measured scan loss of the array, which is shown in Figure 23. Also plotted is the computed scan loss of the antenna, which for this antenna is essentially the element pattern.

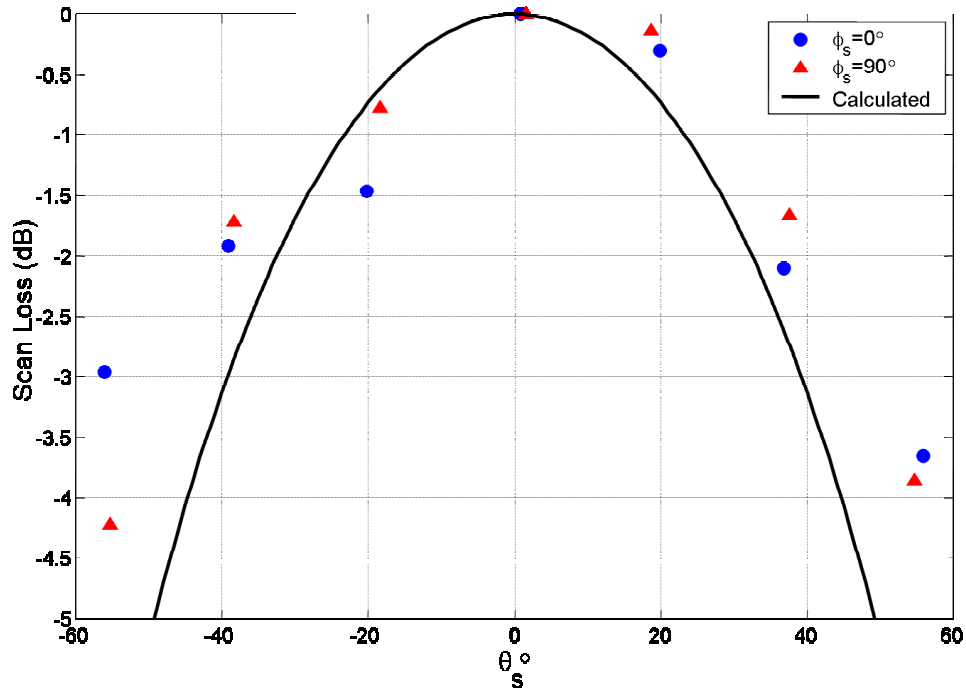


Figure 23 – Measured and Calculated Scan Loss of the Boeing ICAPA Antenna at 19.85 GHz.

Conclusion

This report has described and presented the results of a measurement program conducted to determine the pattern performance of the Boeing ICAPA Antenna as a function of scan angle. Additionally, a computer model of the antenna was developed under this program. The model accurately predicts the performance of the antenna within the error of the measurements. Subsequently the model can be used to enable studies of the antenna to facilitate the use of the antenna as a communication testbed.

References

- [1] Grant Erickson, “ICAPA Receive Antenna System Operators Instruction Guide, Revision A,” Contract F196288-90-C-0168, Boeing Defense & Space Group, Kent, WA, May 12, 1994.
- [2] K.M. Lambert, G. Anzic, R.J. Zakrajsek and A.J. Zaman, “An Overview of the Antenna Measurement Facilities at the NASA Glenn Research Center,” NASA/TM—2002-211883, October 2002.

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1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE October 2003	3. REPORT TYPE AND DATES COVERED Final Contractor Report	
4. TITLE AND SUBTITLE Measured Radiation Patterns of the Boeing 91-Element ICAPA Antenna With Comparison to Calculations			5. FUNDING NUMBERS WBS-22-322-20-04 NAS3-00145	
6. AUTHOR(S) Kevin M. Lambert				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Analex Corporation 3001 Aerospace Parkway Brook Park, Ohio 44142			8. PERFORMING ORGANIZATION REPORT NUMBER E-14161	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001			10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA CR-2003-212603	
11. SUPPLEMENTARY NOTES Project Manager, Thomas Burke, Systems Engineering Division, NASA Glenn Research Center, organization code 7800, 216-433-5172.				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified - Unlimited Subject Category: 33 Available electronically at http://gltrs.grc.nasa.gov This publication is available from the NASA Center for AeroSpace Information, 301-621-0390.			12b. DISTRIBUTION CODE	
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14. SUBJECT TERMS Phased arrays; Antenna radiation patterns; Antenna measurements; Antenna simulation			15. NUMBER OF PAGES 22	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	